Conformal and Spectrally Agile Ultra Wideband Phased Array Antenna for Communication and Sensing

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Outline

State of the Practice & State of the Art

UWB TCDA Concept and Implementation

Digital Beamforming Concept and Implementation

UWB Phased Array Applications

Benefits/Limitations of Phased Arrays

Benefits

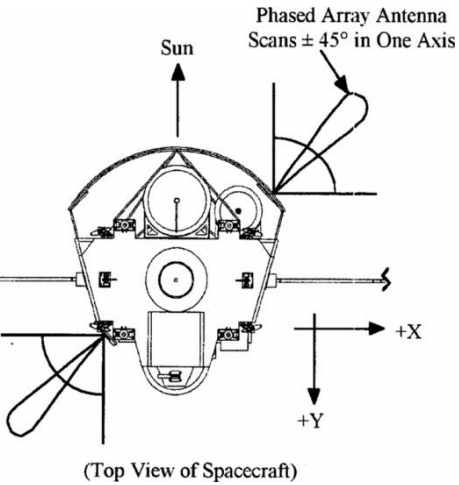
- Graceful degradation
- Mechanical simplicity
- Multi-function
- Agile
- Conformal
- Size, Weight

Limitations

- Narrowband/fixed frequency operation
- Broad beams (few elements)
- Low efficiency (10-35%)
- Single Access
- High cost

Examples of SoP Phased Arrays for Space Applications

MESSENGER



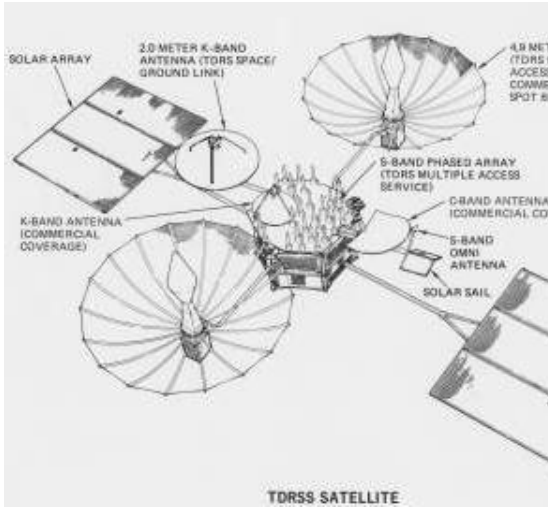
- 2 X-band arrays on board
- 208 slot elements
- 1-D scanning to 45°, 4-bit phase shifters
- 11W RF output, 35% efficiency
- 4.88kg

EO-1

- 64-element X-band array on board
- 2-D scanning to 60° (4 dB loss)
- 5W RF output, 11% efficiency
- 105 Mbps link

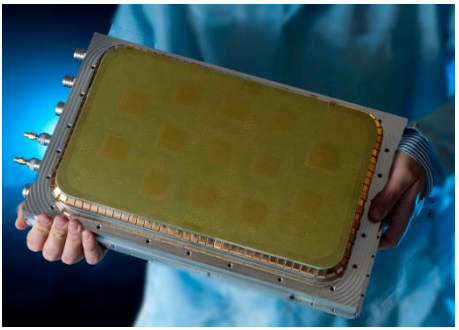
TDRSS

- 30-element S-band, nonuniform array
- 12° scanning



BRAIN (SLS)

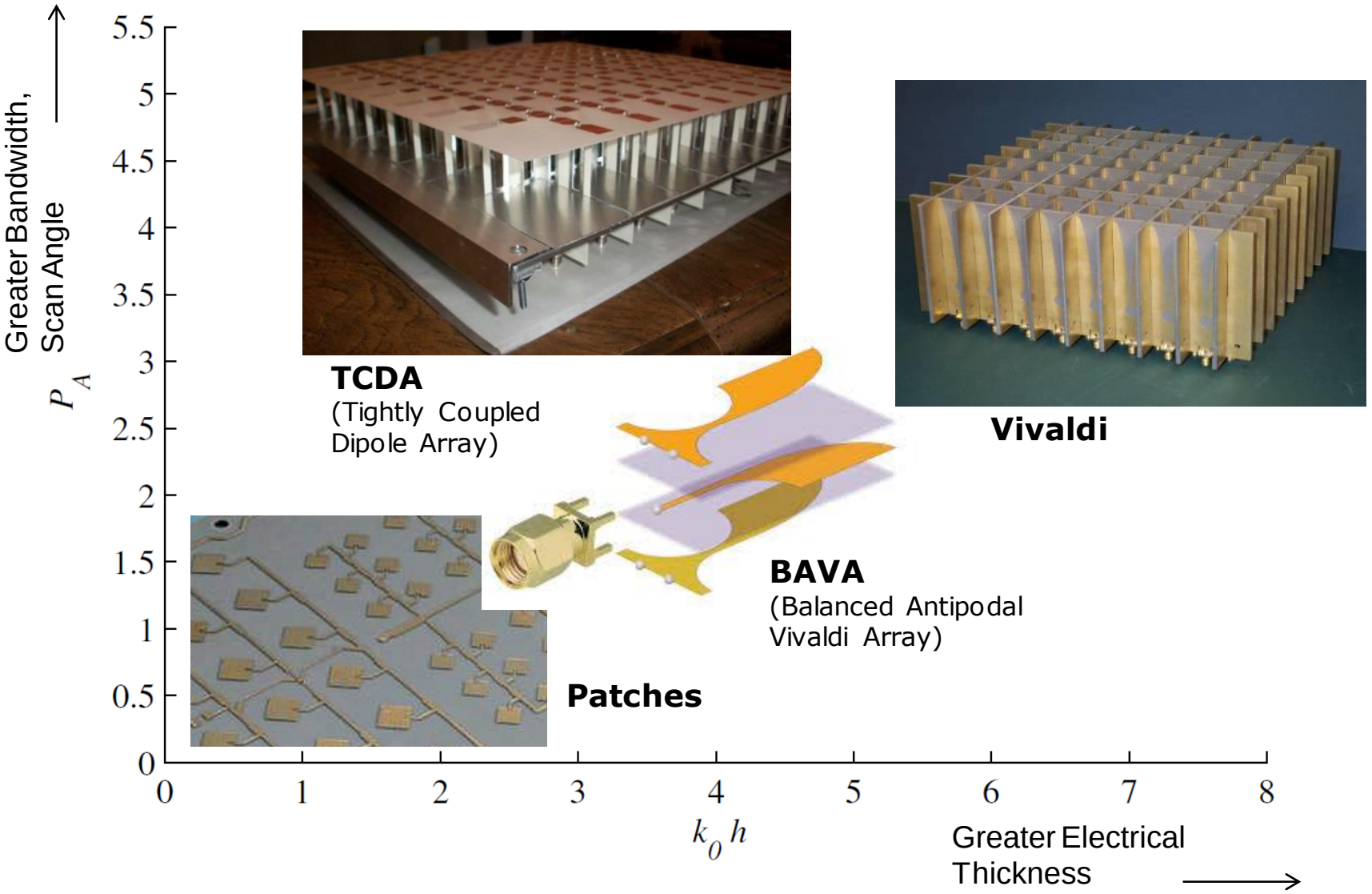
- S-band, very little known



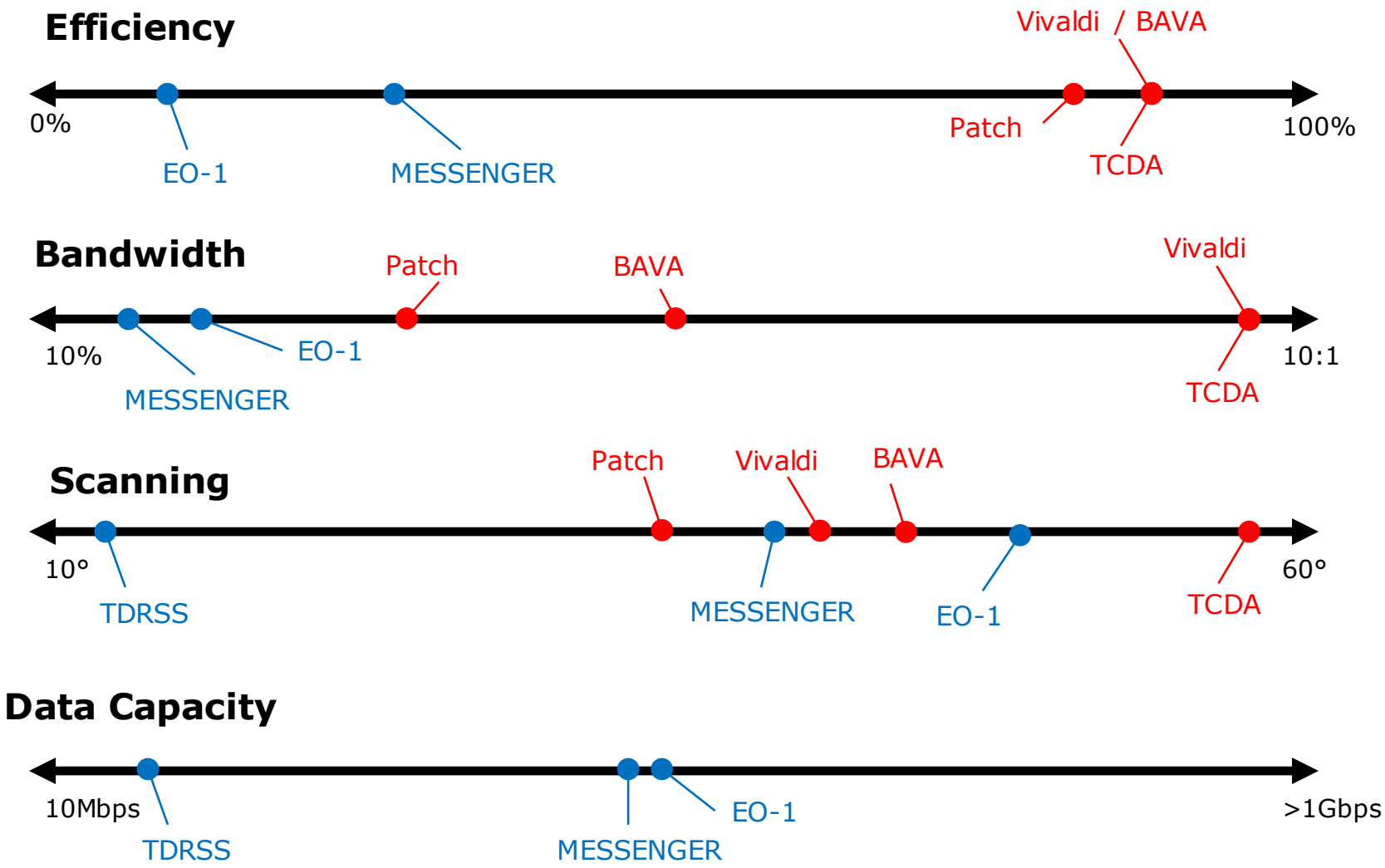
ORION

- 13 patch array, S-band

State of the Art-Trade Off Tables



Expanded Comparisons



DARPA ACT

Arrays for Commercial Timescales seeks versatile array components for S-X band

- Heavily based on analog reconfiguration
- Goals and technology limited to lower frequencies
- No backend integration
- Generally high cost

Benefit/Novelty of our approach:

- Scalable in frequency and size
- Full system integration
- Software-defined operation

http://www.darpa.mil/program/arrays-at-commercial-timescales

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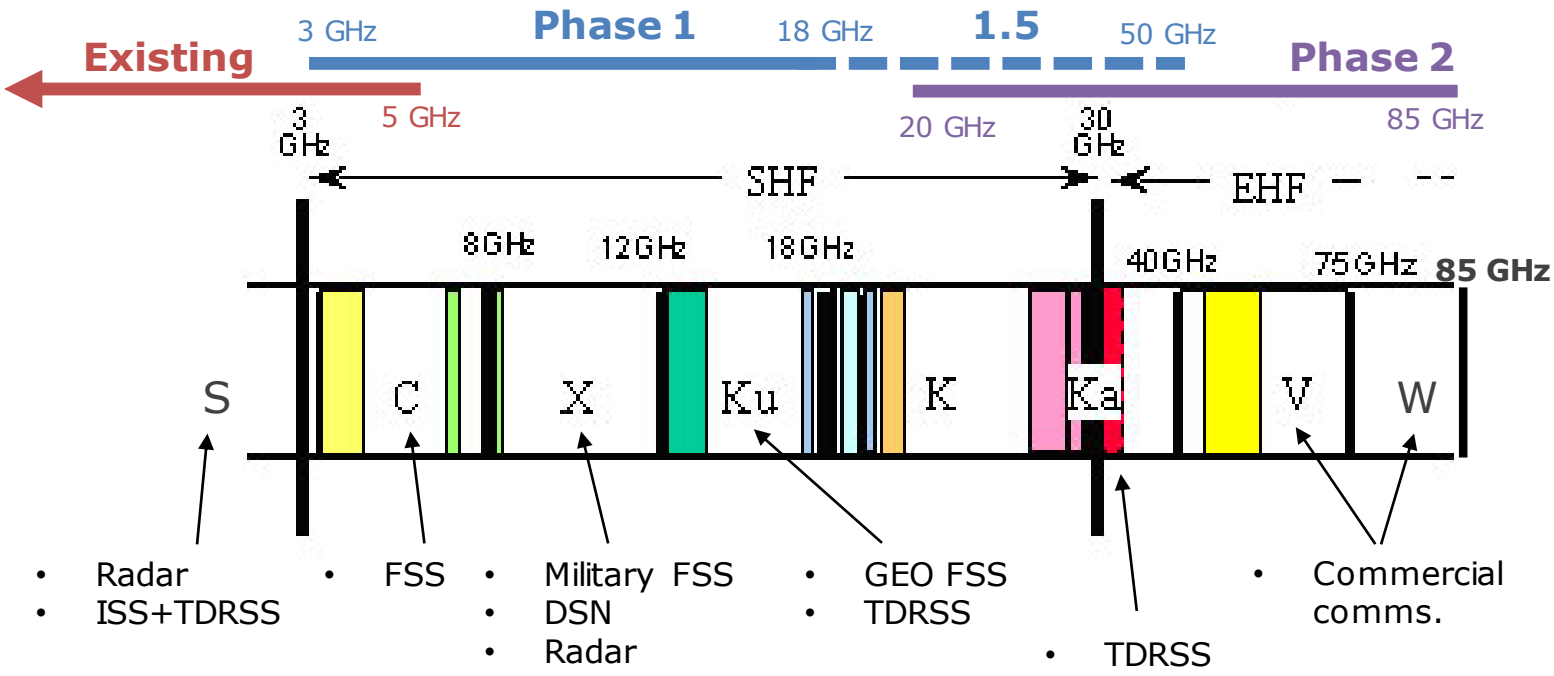
Frequencies of Interest

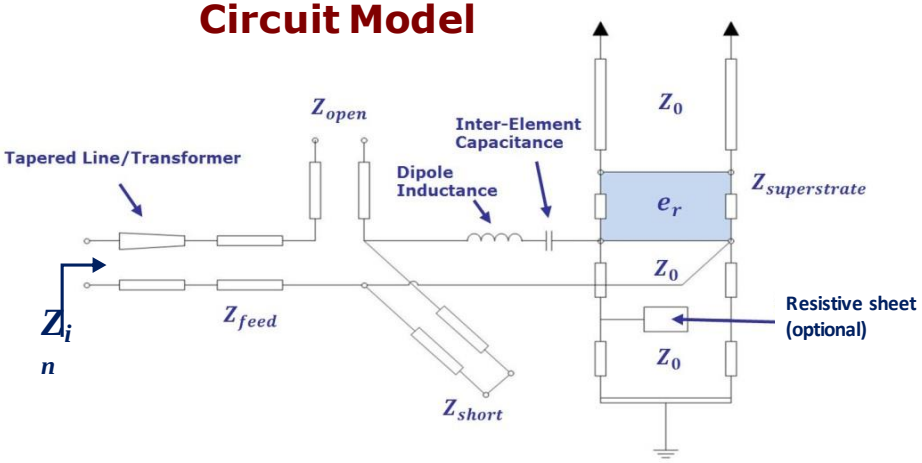


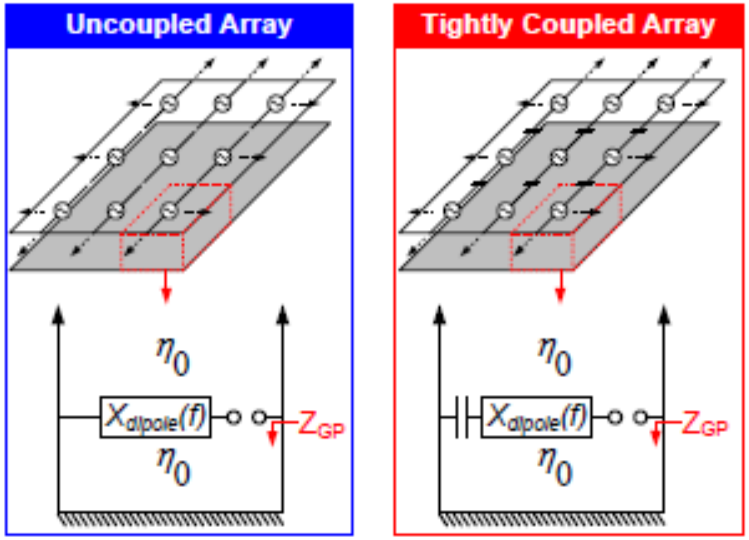
- Need for integration of multiple functions to reduce SWaP
- Need access to high data-rate comms and high resolution imaging, across fragmented spectrum
- Should be low cost

TCDA Background

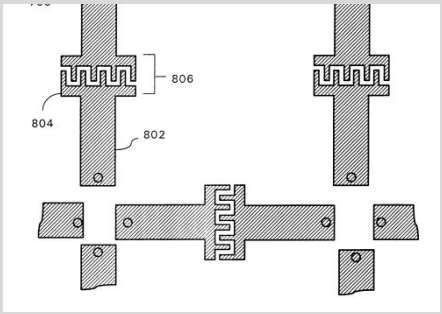
Tightly Coupled Dipole Arrays (TCDAs) utilize capacitive coupling between elements to support low frequencies across multiple elements.

Circuit Model





[1] Munk's Current Sheet Array (CSA) introduces inter-digital capacitors to achieve 4:1 BW

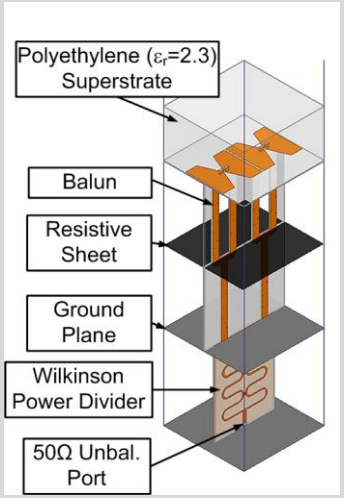


[2] Doane adds integrated balun to demonstrate TCDAs with >7:1 BW and $\lambda_{low}/14$ profile

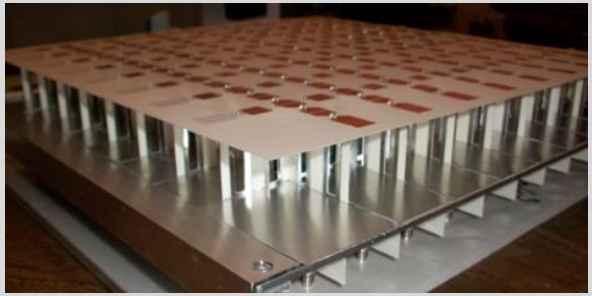
[1] Munk, "CSA"; [2] Doane, "TCDA-IB"

Expanded Background

[3] Moulder designs loaded TCDA with >10:1 bandwidth and $<\lambda_{low}/18$ profile; 14:1 infinite array bandwidth (some loss)



[4] Dual-polarized, lossless TCDA demonstrated with 6:1 BW while scanning to ±60°; 8:1 at broadside



However…

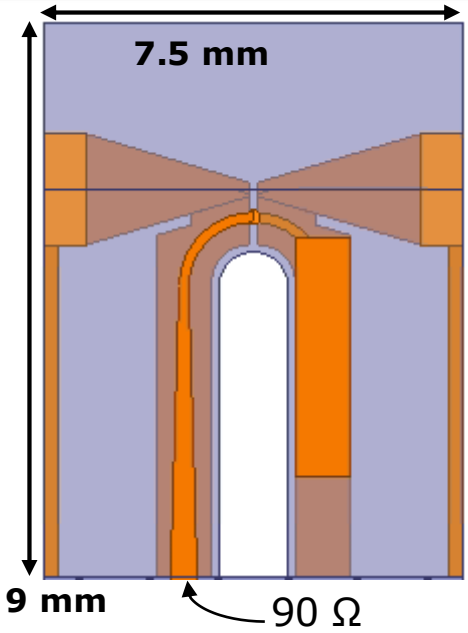
All previous work at <5GHz

Must extend operation to Ku, Ka, and mm-Wave bands

- Fabrication limitations
- Cannot be simply scaled

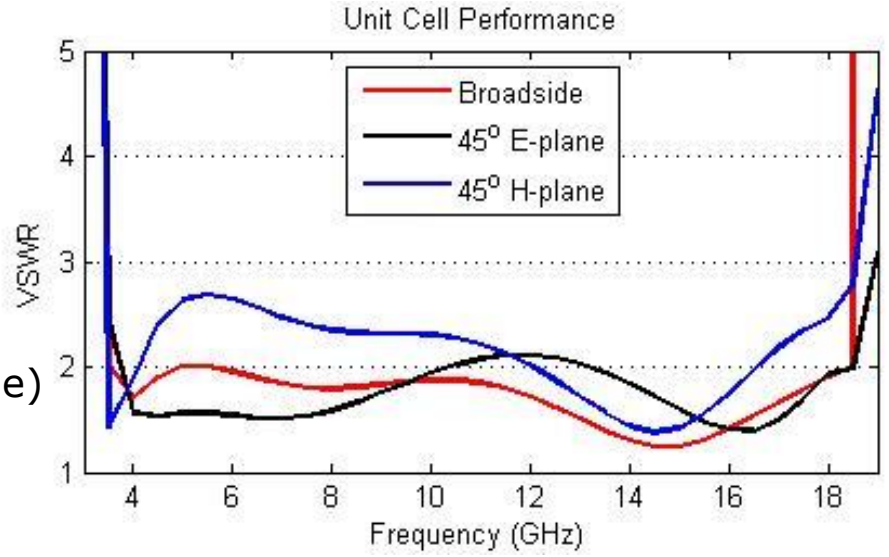
[3] Moulder, "SESLA"; [4] Novak, "UWB Antennas for Satellite Applications"

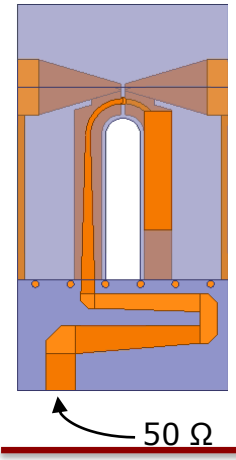
18GHz Proof of Concept

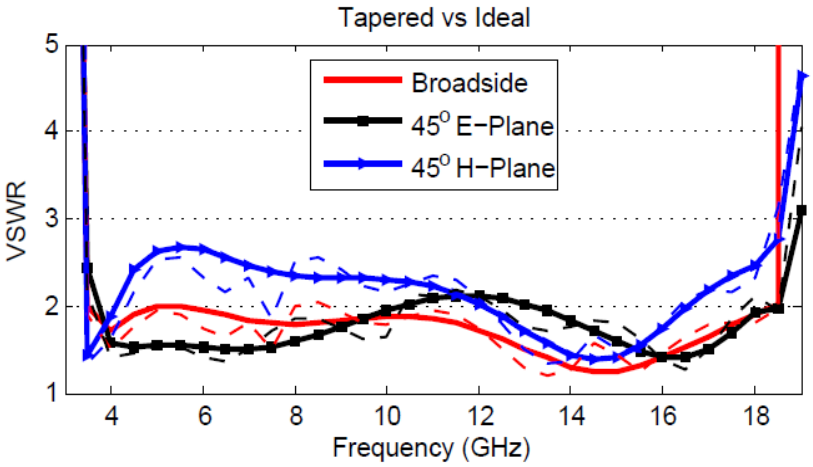


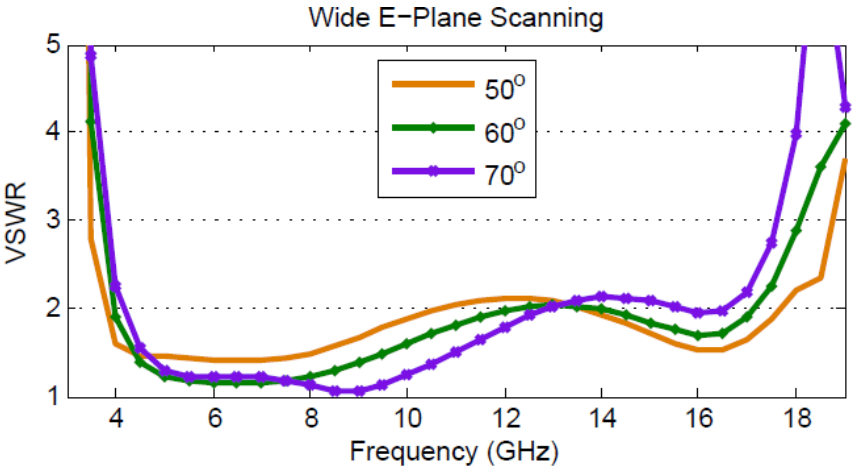
3-layer PCB
8 mil (200um)
feature size
- Can be scaled to higher frequencies

3.5-18.5 GHz
VSWR < 2 (Broadside)
VSWR < 2.6 (scan)









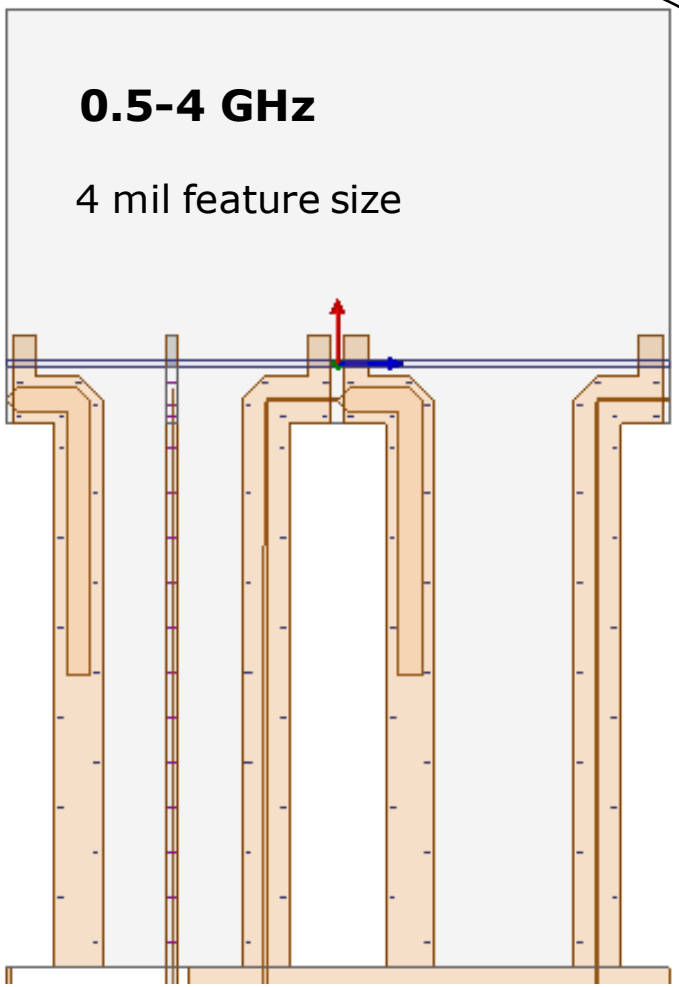
Linear taper to 50 ohm (dashed) approaches nominal 90 ohm (solid) performance

VSWR<2.2 at 70° E-plane
4-17.25GHz (88% of Broadside BW)

What About Even Higher Frequencies?

Previous Works

50mm



0.5-4 GHz

4 mil feature size

Array and feeding network are fabricated on Printed Circuit Board (PCB) which can support down to 3 mil (~75um) features.

Groundplane and superstrate are CNC milled

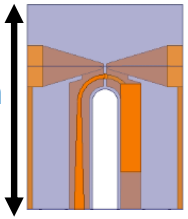
Ku-TCDA

At 18 GHz, nowhere near the limit for PCB fabrication!

3.5-18.5 GHz

8 mil features

10mm



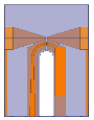
Ka and Millimeter Wave

With minimal alteration this design can scale to Ka and above

7-37 GHz

4 mil

5mm



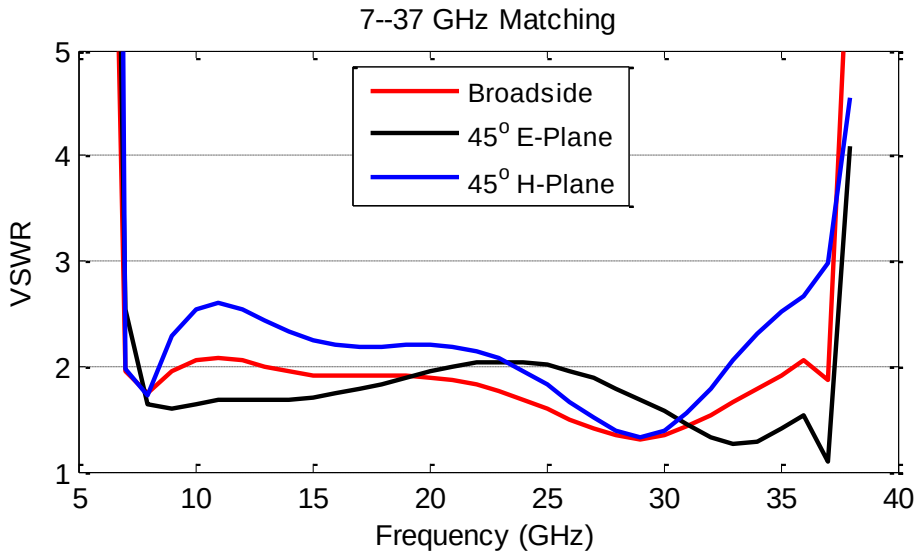
9-49 GHz

3 mil

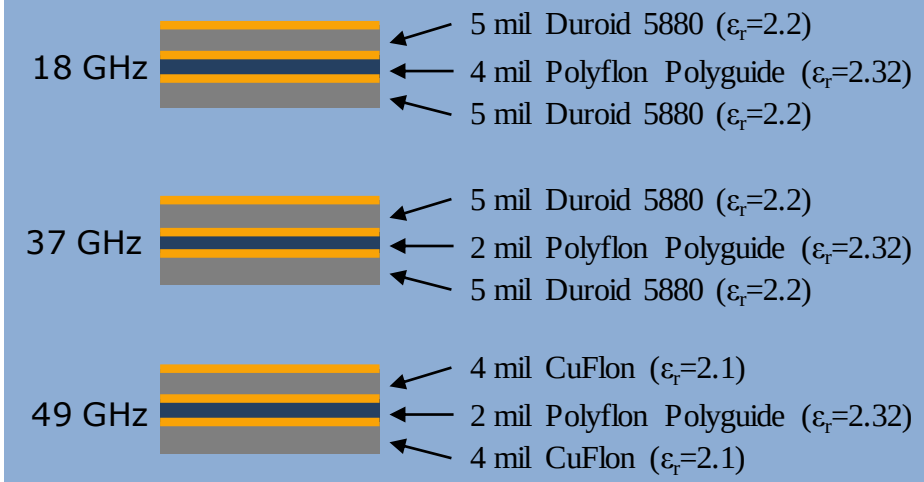
(State of Practice)

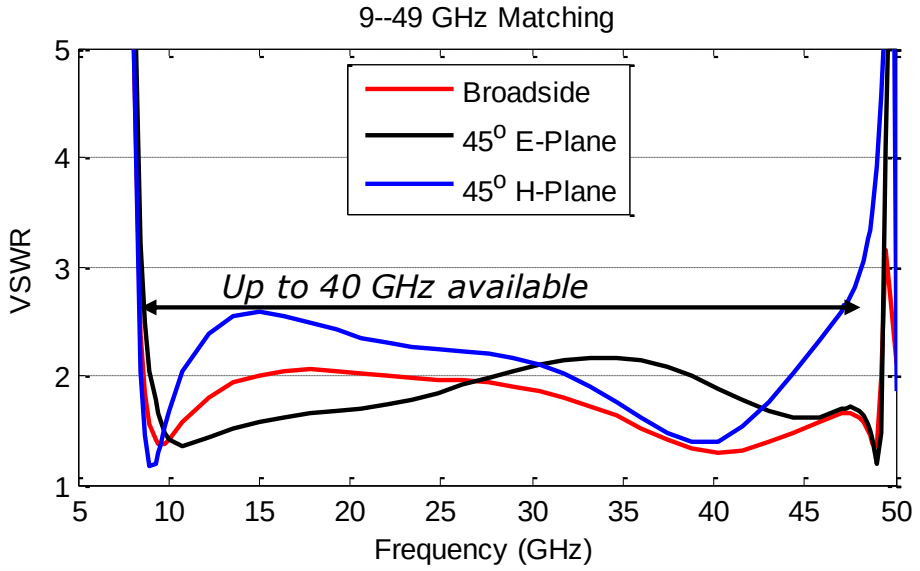
3.75mm

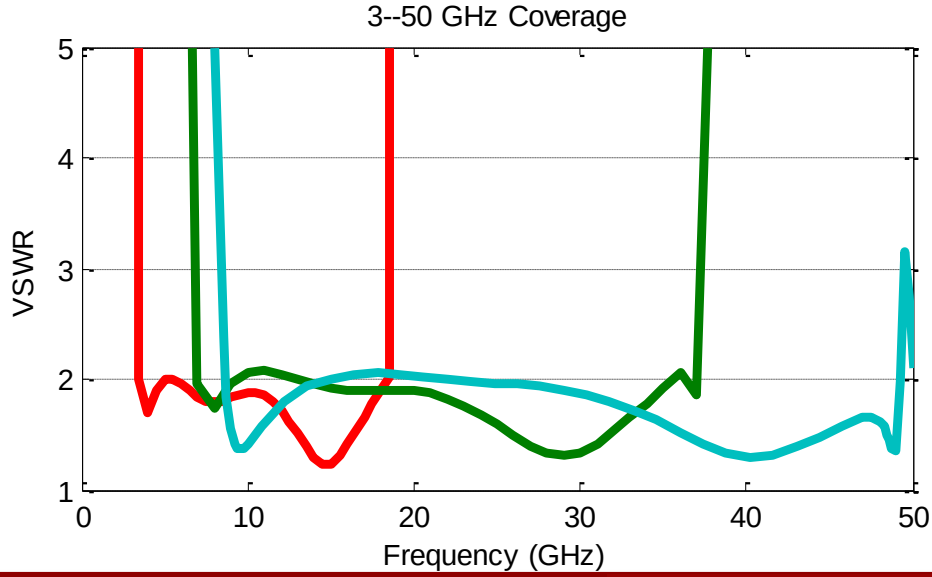
Scaled Arrays with Real Materials



Layer Stacks:



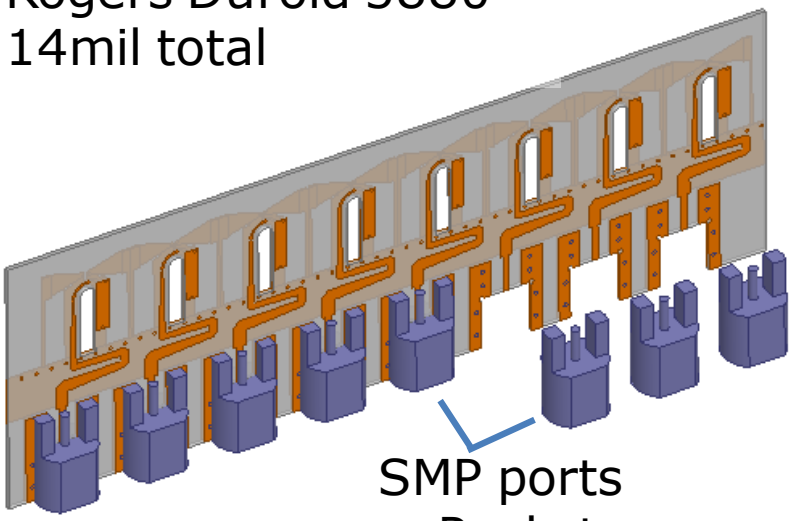




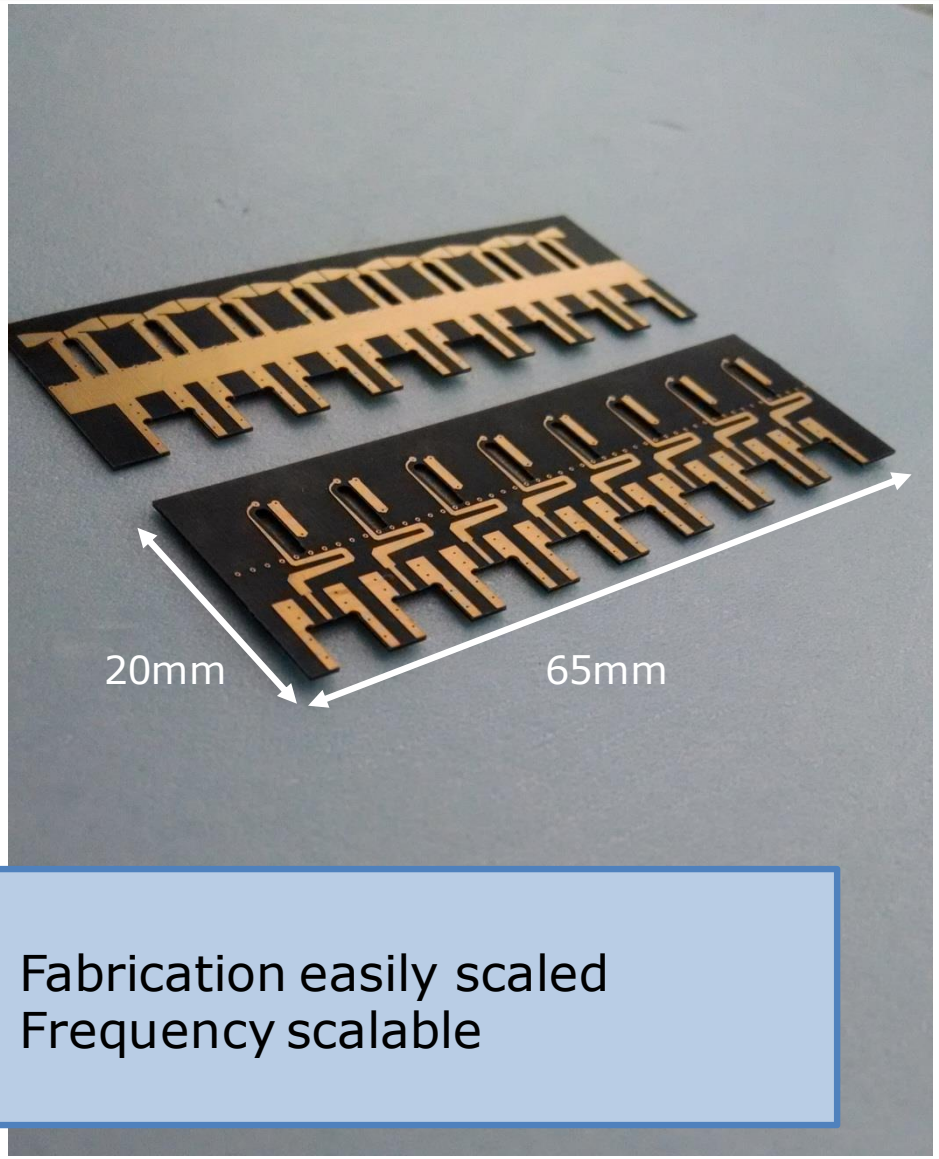
Novak, Miranda, Volakis, "Ultra-Wideband Phased Array Antennas for Satellite Communications up to Ku- and Ka-Band", IN SUBMISSION

Ku Array Fabrication in PCB

- Four-layer PCB
- Rogers Duroid 5880
- 14mil total

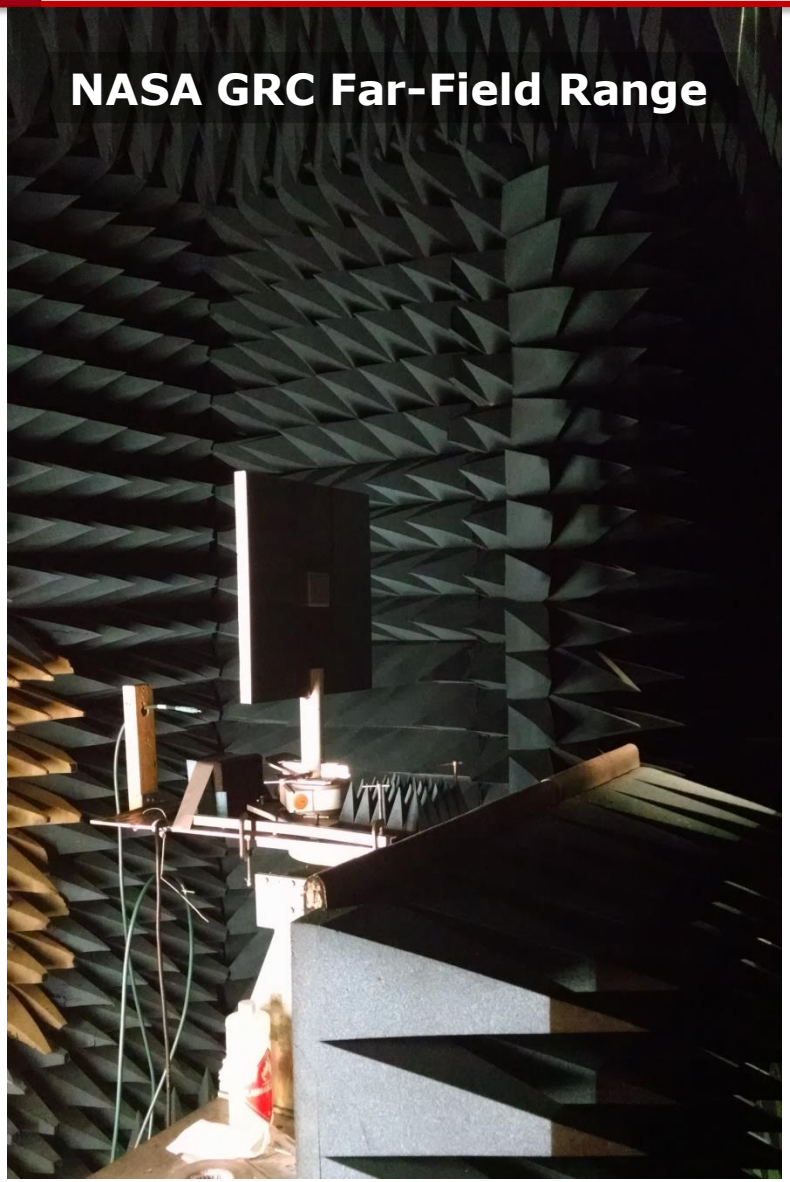


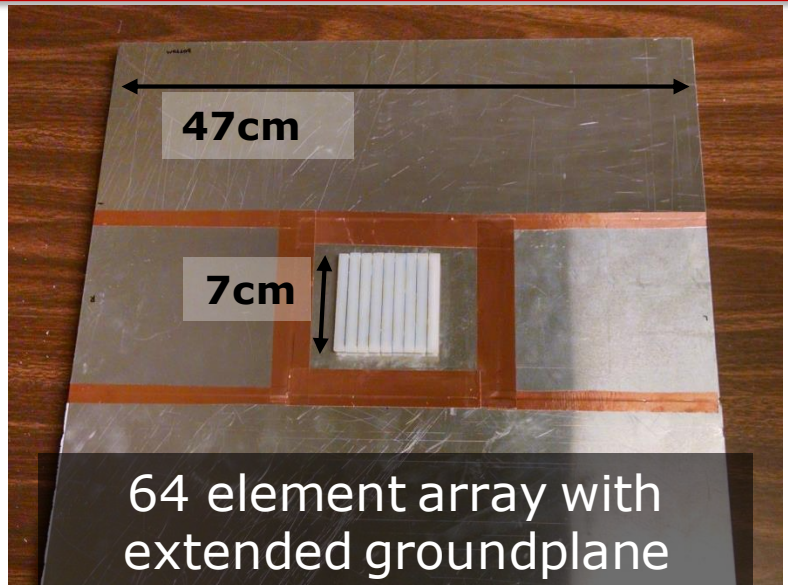
SMP ports
- Push-to-connect
- 4mm wide

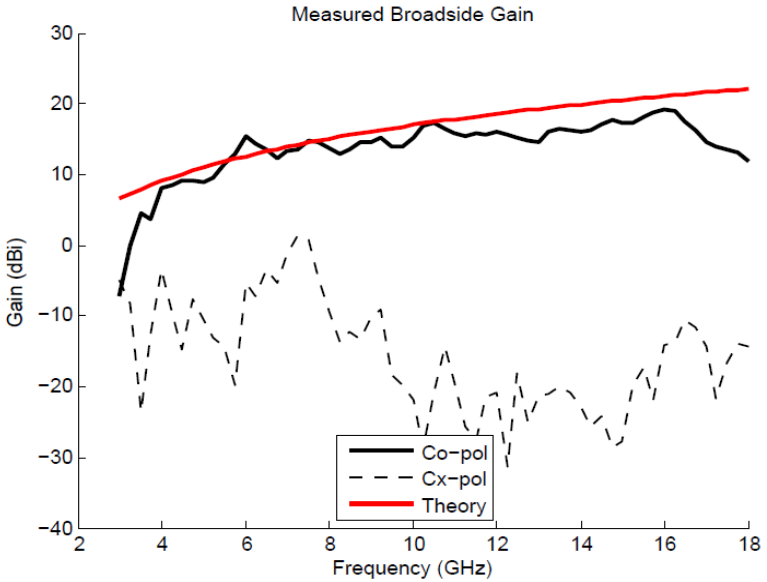


- All elements identical
- Low-cost fabrication
- Fabrication easily scaled
- Frequency scalable

Measurement Setup





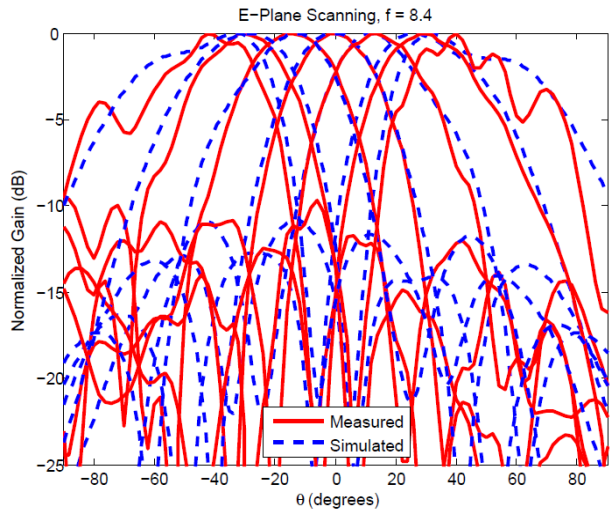


Details in upcoming "Wideband Array for C, X, and Ku-Band Applications" IEEE APS 2015

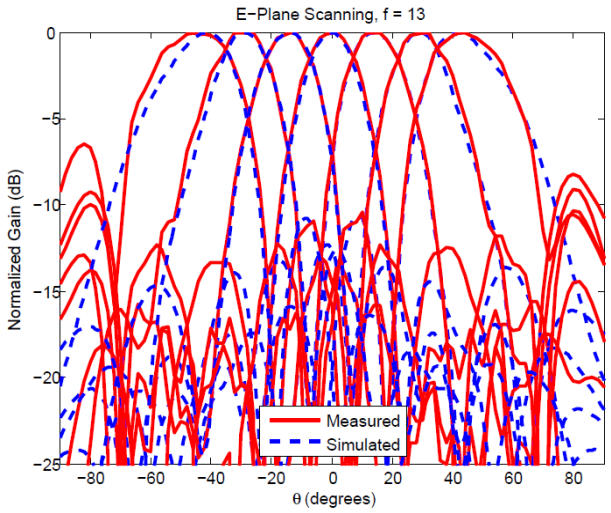
Scan Patterns: 8.4 GHz, 13GHz, 17.5GHz

E-Plane

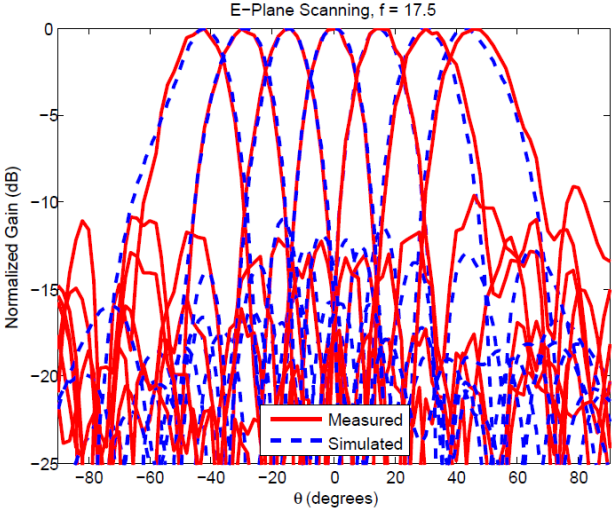
8.4GHz

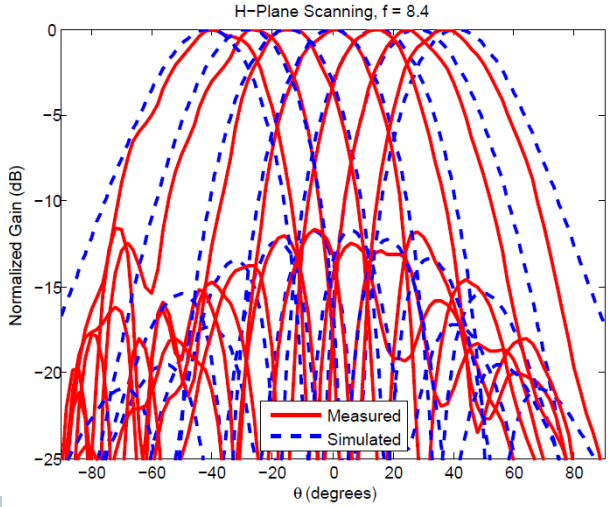


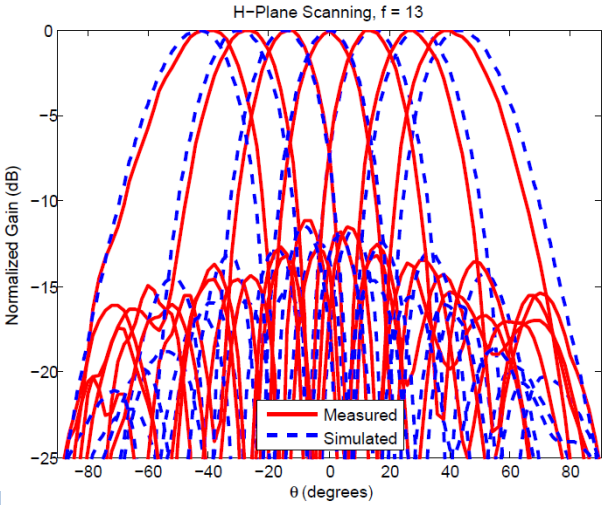
13GHz

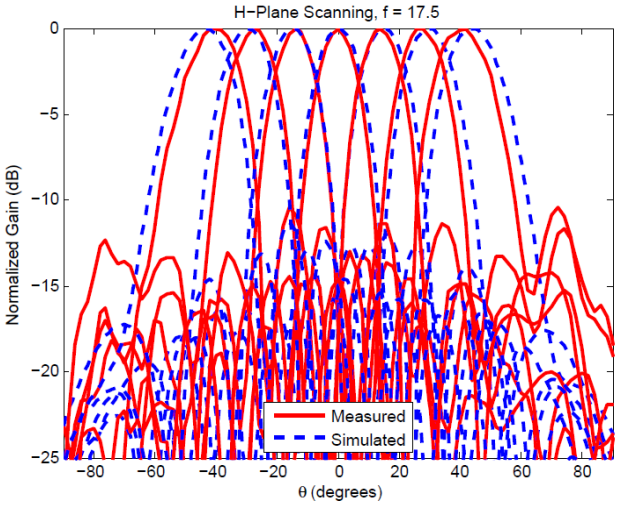


17.5GHz





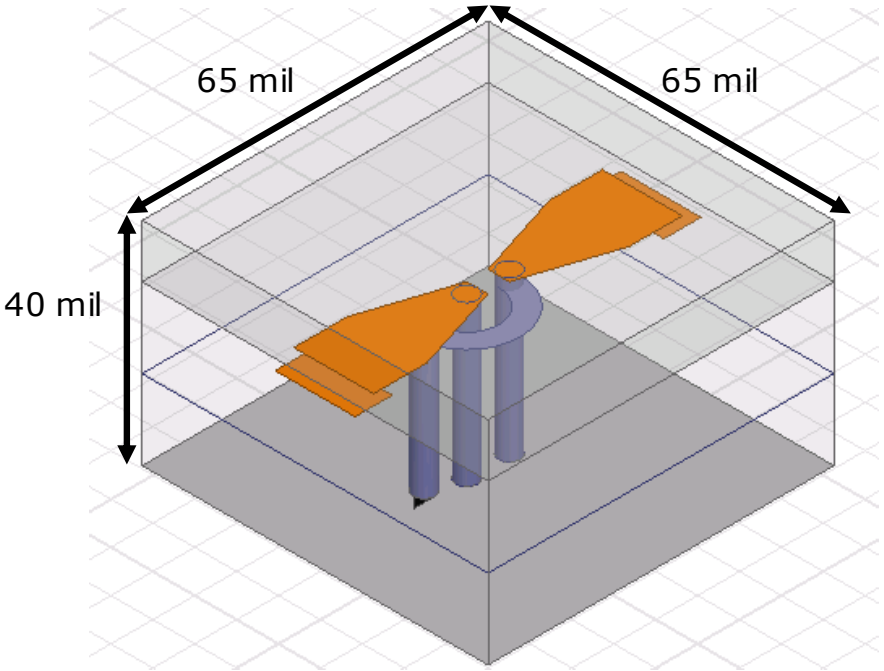




H-Plane

Details in upcoming "Wideband Array for C, X, and Ku-Band Applications" IEEE APS 2015

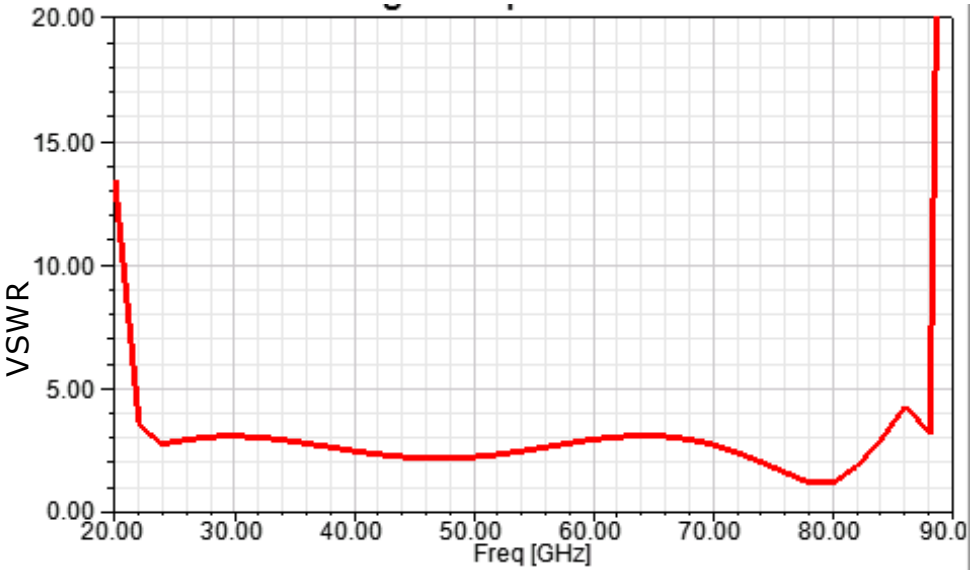
Ka to mm-Wave Concept



Nominal band: 24-86GHz

λ_{hi} = 3.49mm (~140mil)

- Using Low-Temperature Co-Fired Ceramic (LTCC) or Multilayer Organic laminates (MLO)
- Requires planar or extremely simplified balun for all-in-one fabrication
- Additional matching stages can be inserted below groundplane



Non-optimized broadside VSWR

- Not interested in matching as much as resonance-free band

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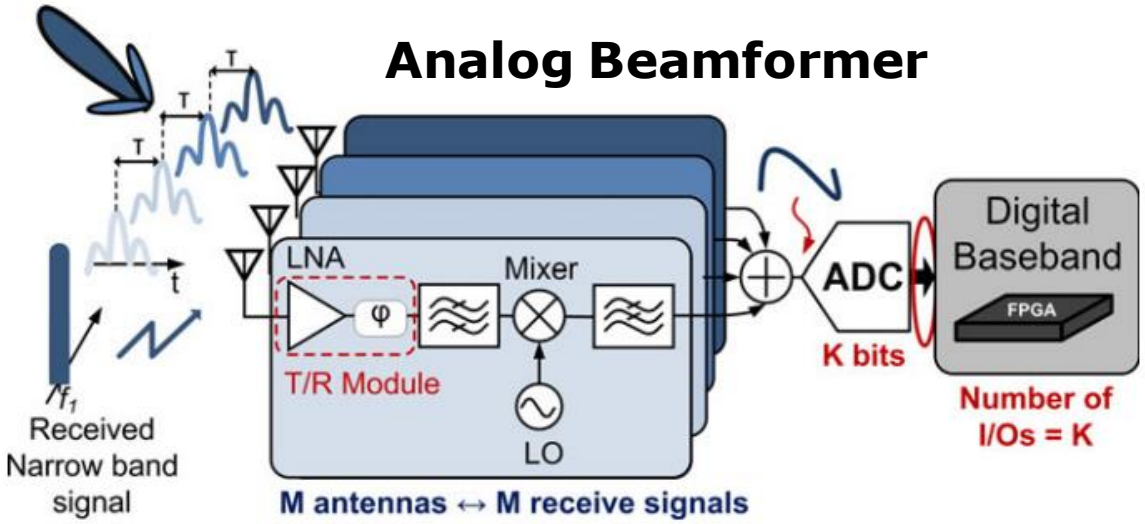
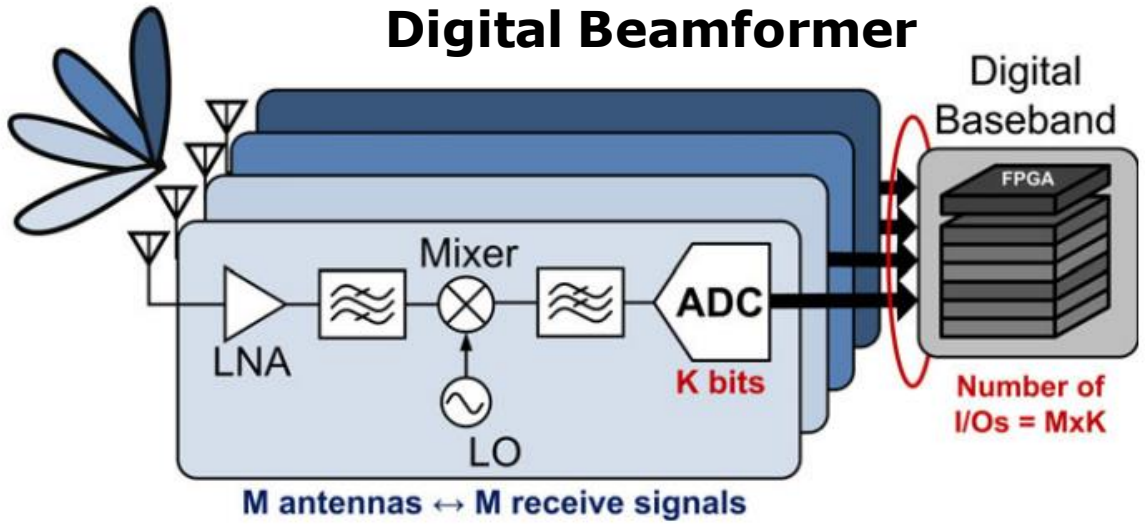
Current SoA Beamformers

Analog Beamformer



- Well understood
- Single Access
- Many phase shifters
  - Expensive
  - Inefficient
- Narrowband

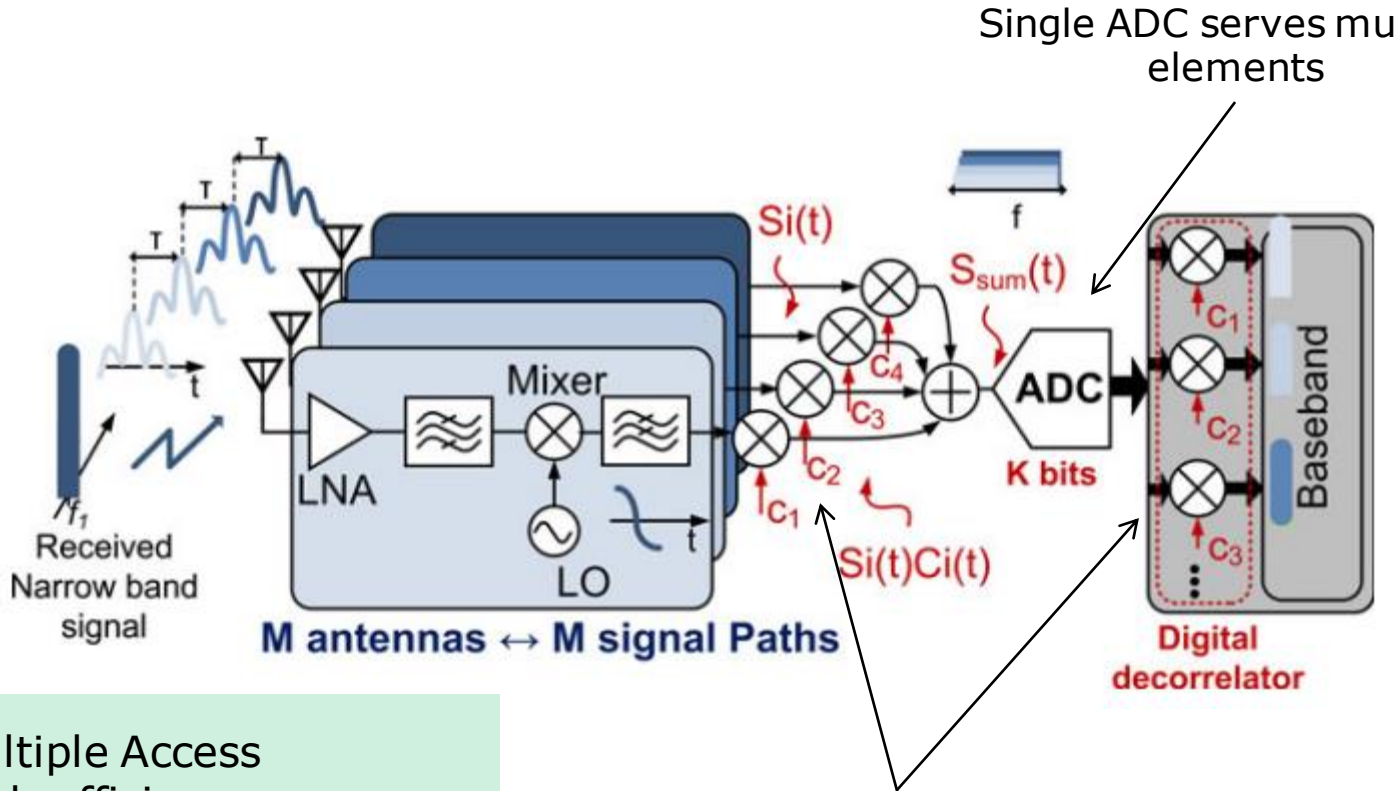
Digital Beamformer



- Multiple Access
- High efficiency
- Many ADC
  - Power Hungry
  - Large area
- Heavy FPGA requirements

New Digital Beamforming Concept

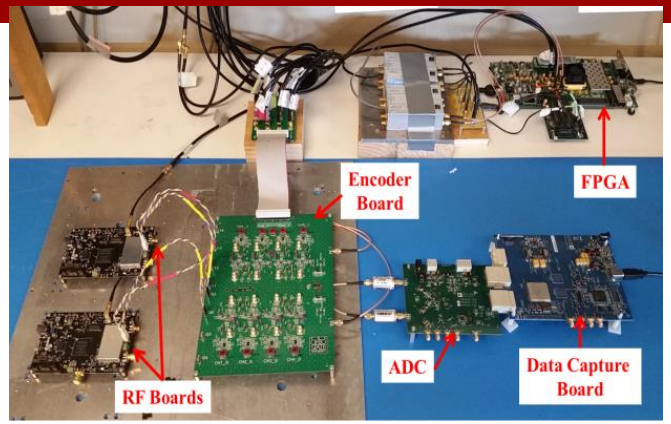
On-Site Coding Digital Beamformer



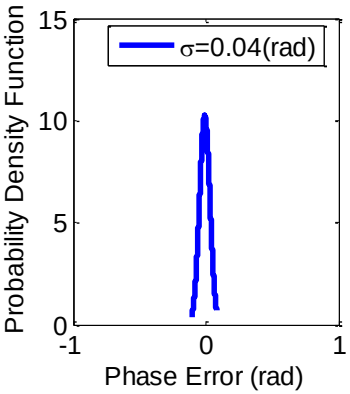
- Multiple Access
- High efficiency
- Reduced ADC and FPGA
- Broadband

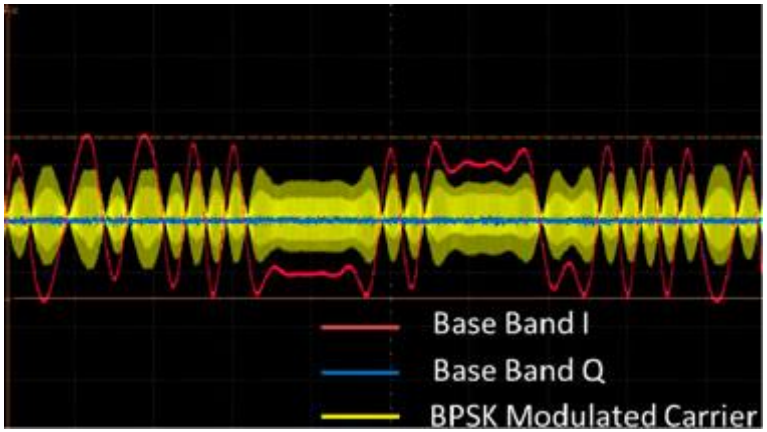
System Implementation

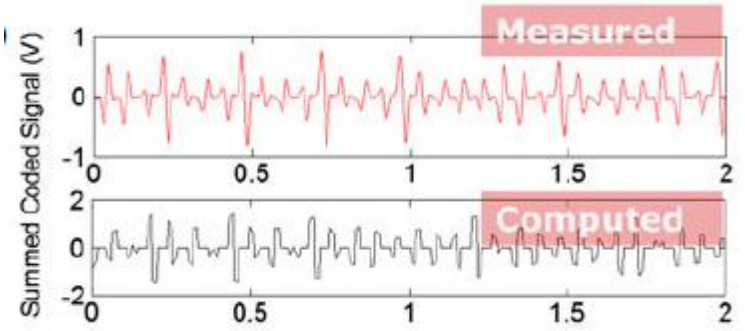
4-channel Beamformer



- 4-chanel system has been demonstrated at 2GHz
- Demonstration up to 12GHz being prepared



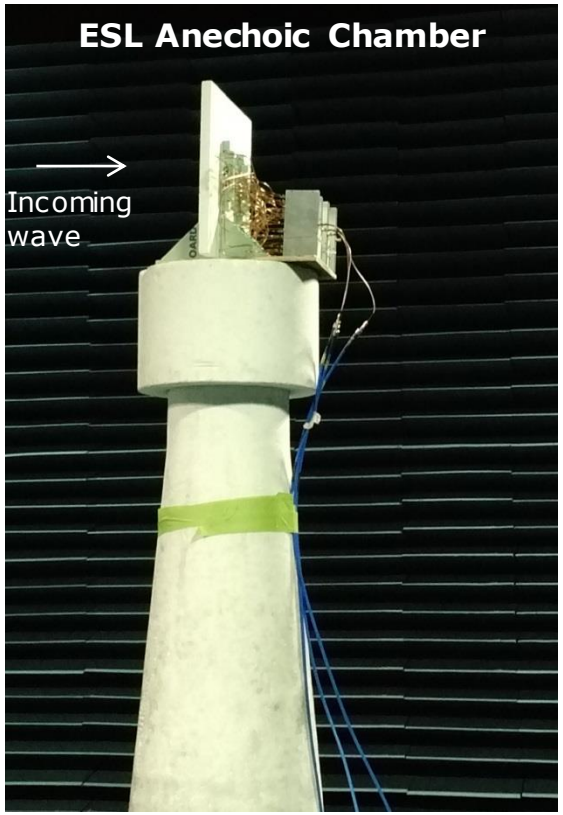




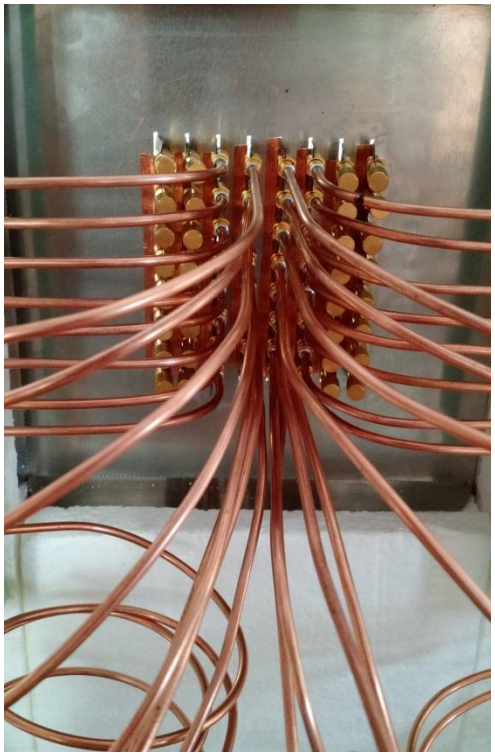
Utilizing on-site coding in analog signal path, we realize hardware-reduced digital beamforming:

- Up to 10x reduction in ADCs
- Wideband, multiple beam operation
- Fast scanning
- Software-defined operation

Digital Beamforming up to 10 GHz



- Columns of 8 elements routed to power combiners
- 4 channels routed, maximum 3 measured due to equipment malfunction
- Demonstrate azimuthal scanning in H-Plane
- Demonstrate Direction-of-Arrival estimation from 2 channels
- Receive and process separate signals at 6 and 10 GHz
- Beam patterns being compared against previous measurements



Measurements conducted 9/14 and 9/15, results being processed.

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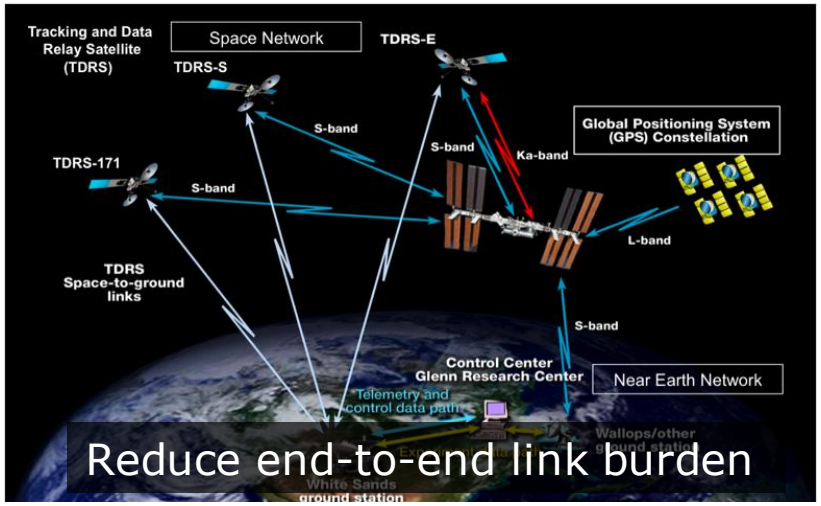
UWB Phased Array Applications

Smart Relays



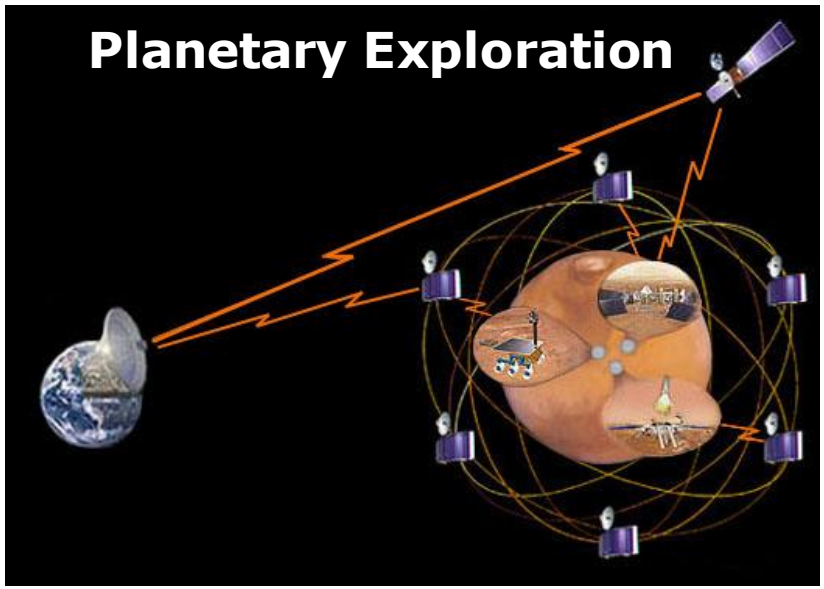
Reduce end-to-end link burden

[1]

Software-Defined Radio

- Spectral agility
- Future-proof
- Coding & waveform flexibility
- Multi-Gbps link capability

Planetary Exploration



[2]

SmallSat/CubeSat

- Low cost exploration
- Potentially distributed architecture for communication and sensing

[1] NASA GRC CoNNeCT/SCaN Testbed, [2] NASA JPL

Summary / Future Work

Summary

- We have an ultra-wideband antenna which is:
  - Low cost, low profile, low weight
  - Scalable in size and frequency
- Paired with novel digital beamforming architecture
  - Multiple access and simultaneous multi-beam scanning
  - Up to 10x reduction in ADC count (thus power and size)
- Both fabricated and measured

Future Work

- Fabricate and measure 20-80 GHz array
- Build an integrated, RF–digital, mm-Wave phased array

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